EFFECT OF THE INTEGRATED BRAKE-ACCELERATOR PEDAL ON REDUCTION OF BRAKE ACTUATION TIME

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THESIS

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ABSTRACT

This experiment was performed to evaluate the effect of the integrated brake-accelerator pedal on the reduction of brake actuation time. The pedals were designed so that the drivers could accelerate with the toe of their right foot while the right foot was resting on the brake. Pedal I was of a hinged design and Pedal II was of a one piece design. 48 Ss were used to test the two integrated brake-accelerator pedals at angles of 45° and 60°. The task was to depress the accelerator to a required level and then depress the entire pedal when a red light was activated. The brake actuation time was the time elapsed between onset of the light and 1/16th inch depression of the pedal. Results showed a significant difference ($p < .01$) between the pedals with the one piece design performing the fastest. The mean brake actuation time for this pedal at 60° angle was 222 milliseconds. This is 101 milliseconds less than the mean brake actuation time of the next fastest integrated brake-accelerator pedal design. The results support further experimentation with the one piece pedal with the prospect of further reducing the brake actuation time.

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I. THE PROBLEM

The automobile is the man-machine system that almost every family in the United States owns, and at the same time it is the deadliest man-machine system in the United States with more than 50,000 deaths to its credit annualy since 1967.

There are various ways of improving the safety of the automobile which include more effective human engineering of the automobile, the highway system and the traffic system.

More effective human engineering of the automobile includes the design of the automobile controls to make the most effective use of human capabilities. Research has been conducted to find more efficient methods for the driver to stop the automobile, and there has been some reduction in brake actuation time through the use of integrated brake-accelerator pedals. These are pedals which combine control of the accelerator and brake in one pedal.

This research is the development and initial testing of two integrated brake-accelerator pedals in an effort to further reduce brake actuation times.

II. THE LITERATURE

The ability to stop a motor vehicle quickly is a way to reduce the number of deaths and injuries caused by motor vehicle accidents. Methods on which experiments have been conducted to determine the reduction in brake actuation times are left foot braking and the one pedal brake-accelerator integrated control.

Since the advent of the automatic transmission many drivers have gone to left foot braking. In an attempt to evaluate advantages of left foot braking Belzer and Huffman (1966) conducted an experiment to determine the time saving of left foot braking when compared to the conventional method of braking in which the right foot moves from the accelerator to the brake pedal. They found that left foot braking with the left foot poised on the power type brake had an average time of .247 seconds when using a sample of 48 fifteen year old non-drivers. This time was significantly less (.171 seconds) than the average time of .418 seconds for the same sample using the conventional method of braking.

However, the average braking time for this sample was .425 seconds when the left foot had to move from a position on the floor to the power type brake. Thus, left foot braking when the left foot is on the floor provides no savings in time over conventional braking methods.

At least 17 patents have been granted to inventors for integrated brake-accelerator pedals and Konz, Koe and Kalra (1968) have conducted a series of five experiments to determine the time savings possible in the use of the integrated brake-accelerator pedal.

In their initial experiment they determined that it would be easier to combine the braking function with the accelerator pedal than with the steering wheel because the accelerator foot is in a relatively fixed position while the hands move.

They experimented with a combined brake-accelerator pedal designed by a Mr. C. N. Winkleman and a pedal designed by Mr. B. Koe. The pedal designed by Mr. Winkleman activated the accelerator when the toe was pressed down and activated the brake when the heel was pressed down. There was an interlock between the two controls to prevent simultaneous actuation of both controls.

In the experiment comparing the Winkleman integrated control with a conventional system of clutch, brake and accelerator pedal the following brake actuation times were obtained:

1) .29 seconds to depress conventional brake; starting position - left foot on brake.

2) .45 seconds to depress conventional brake; starting position - right foot on depressed accelerator.

3) .36 seconds to depress Winkleman's combined control; starting position - right foot on depressed accelerator position of the combined control.

The results obtained in this experiment were of the same magnitude in the experiment conducted by Belzer and Huffman for the brake actuation times with the starting position - left foot poised on the brake pedal and right foot on the conventional accelerator.

Next Konz, Koe and Kalra developed an integrated brake accelerator pedal without interlock which accelerated when the toe was depressed and braked when the heel was depressed. They conducted an experiment using 72 subjects (Ss) in which the following results were obtained;

1) .482 seconds to actuate the American Automobile Association reaction timer; starting position - right foot depressed on the accelerator.

2) .435 seconds to actuate the brake in a 1960 Rambler equipped with automatic transmission; starting position - right foot on depressed accelerator.

3) .323 seconds to actuate the integrated brake and accelerator pedal; starting position - depressed accelerator.

In their most recent experiment Konz, Kalra and Koe (1968) used sixteen paid Ss, eleven male and five female, who had an average age of 23 and an average of 5 years driving experience. In this experiment the S was seated on a chair with a stop light (a red cellophane covered 60 watt bulb) about 5 feet in front of him. The S placed his right foot on the experimental pedal and depressed the toe of the experimental pedal. Next, the stop light was activated and the S pressed the heel of the experimental pedal and the actuation time (the time between onset of the stop light and the depression of the heel of the pedal - a distance of 1/16th inch) was recorded.

The intersection of the back of the seat with the seat surface was placed a distance of 50% of the subjects heighth from the heel of the experimental pedal. The pedal was placed at an angle of 45° with the

floor. The cellophane covered red light was placed a distance of approximately 5 feet in front of the S's eyes and 3 feet above the floor. Each S was tested under 5 conditions with 20 times recorded for each condition. Prior to recording the times the Ss were given 3 to 5 practices at each condition.

The average time for each S at each condition was recorded. Of these, the fastest average brake actuation time of all 16 Ss was .2815 seconds and the average of the fastest brake actuation times of each of the 16 Ss was .3314 seconds. A summary of experiments reported here is included as Table I.

Two conclusions can be gleaned from the review of brake actuation experimentation to date. These are;

1) the fastest brake actuation is with the left foot poised on the brake

2) the integrated brake-accelerator pedal does show the possibility of decreasing the critical brake actuation times.

III. THE EXPERIMENT

In the summary of recent brake actuation time experiments (Table I) the shortest actuation time (< .30 seconds) occurred when the Ss had their left foot poised on the brake. Teichner (1954) stated that the preferred limb was several hundreths of a second faster in reaction than the unpreferred limb. Thus, if the right foot could be poised on the brake the brake actuation time should be less than that for the left foot poised on the brake.

Konz, Koe and Kalra (1968) recommended that, "It may even be desirable to automatically disengage one mode if a certain percent of the other mode is actuated."

In light of these facts, two pedals were designed in which the toe of the pedal was the accelerator and the brake was actuated when the entire pedal was depressed 1/16th of an inch. At the time the brake was actuated the accelerator was automatically disengaged. Thus, this pedal allowed the right foot to be poised on the brake and the accelerator was disengaged when the entire pedal was depressed 1/16th of an inch.

Pedal I had a rigid heel and a hinged toe plate which was used to depress the accelerator.

Pedal II had a one piece pedal which could rotate about the brake shaft.

This experiment compared these two pedals at angles with the floor of 45° and 60° in order to determine if there was any significant difference in brake actuation times between them.

IV. METHOD

A. BRAKING APPARATUS

The pedals used in this experiment were designed by Dr. G. K. Poock, Major T. J. Toben and Lieutenant Colonel A. E. West. Both pedals were designed to disengage the accelerator when the brake was applied.

The pedals were designed to allow the driver to ride with his right foot on the brake while accelerating with the right foot. In order to activate the brakes the driver just pushed the entire pedal down. This activated the brakes and disengaged the accelerator.

Pedal I (shown in Figure 1) used a hinged foot pedal in which the heel portion was held at a fixed angle with the brake activating post.

Pedal II (shown in Figure 2) used a one piece pedal which was free to pivot about the brake post at the heel of the pedal.

Both pedals were spring supported using 18 lb. per inch spring rate on the brake shaft and 4.5 lb. per inch on the accelerator shaft. The brake shaft spring support allowed the foot to rest on the brake without activating it.

The pedals were 12 inches long and 3.5 inches wide with a $\frac{1}{2}$ inch heel support at the base of the pedal to keep the foot from slipping off.

The accelerator shaft activated a linear potentiometer which controlled the voltage into a voltmeter which acted as a speedometer.

The brake shaft activated a micro switch after it had been depressed 1/16th of an inch.

B. TEST APPARATUS

The test "vehicle" is shown in Figure 3. The apparatus was mounted on a plywood base and consisted of a truck seat, a steering wheel and post, the accelerator speedometer system, the brake pedal system and the red stop light.

The timing was done in milliseconds by using an audio oscillator that generated 1,000 cycles per second which was fed into an electronic counter. A switch activated the red stop light, the audio oscillator and the electronic counter; when the brake pedal was moved 1/16th of an inch it activated a micro switch which turned off the stop light and stopped the audio oscillator. Therefore, the count on the electronic counter was the brake actuation time in milliseconds.

The brake pedal support was fitted for both pedals and it allowed the pedals to be tested at a 45° and a 60° angle with the floor.

The switch which activated the light, oscillator and counter made an audible click sound.

C. SUBJECTS

The Ss were 48 officer graduate students of the Operations Analysis curriculum at the United States Naval Postgraduate School. Their average age was 30 years and their driving experience varied from 11 years to 23 years. They served in the experiment as unpaid volunteers.

D. PROCEDURE

The Ss were each randomly assigned to one of eight random test sequences. The purpose of the experiment was explained to the Ss. Then the seat was adjusted so that the distance from the intersection of the back rest surface with the seat surface to the heel of the pedal was 50% of the Ss' heighth. Next, the subject was shown the sequence of the test: accelerate so that the simulated speedometer registered the proper despression of the accelerator pedal; then look at the red light which was placed approximately 5 feet in front of the Ss and 3 feet above the floor; push the entire pedal down as soon as the light appears, and the light will go out; the time will be recorded from the time the red light goes on until the time the brake is activated.

Each pedal was tested at an angle of 45° with the horizontal and at an angle of 60° with the horizontal. The angle of the pedals with the vertical was 0° for all tests. Eight sequences of testing were used.

The S was given an initial practice of two to five trials at each condition. Then 4 times were recorded for each condition.

The recording of the times and resetting the counter ensured that the time between successive stimuli was greater than 10 seconds.

The Ss were allowed to rest while the angle and/or the pedal was being changed. The test was administered to each of the Ss in approximately 12 minutes.

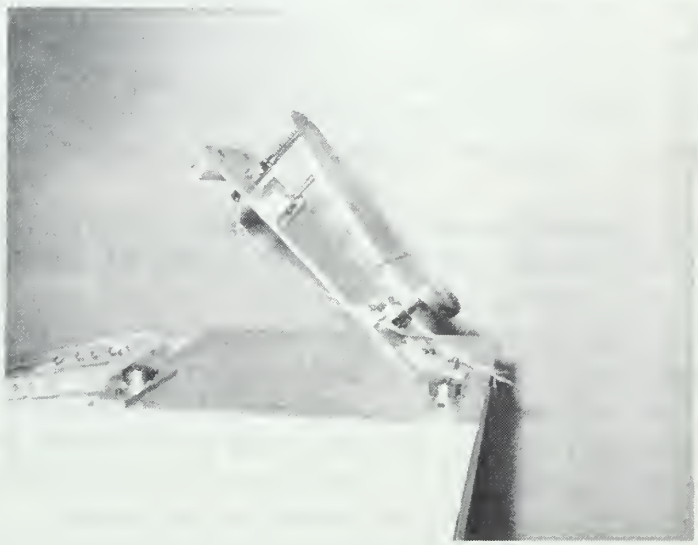

FIGURE 1. Pedal I

FIGURE 2. Pedal II

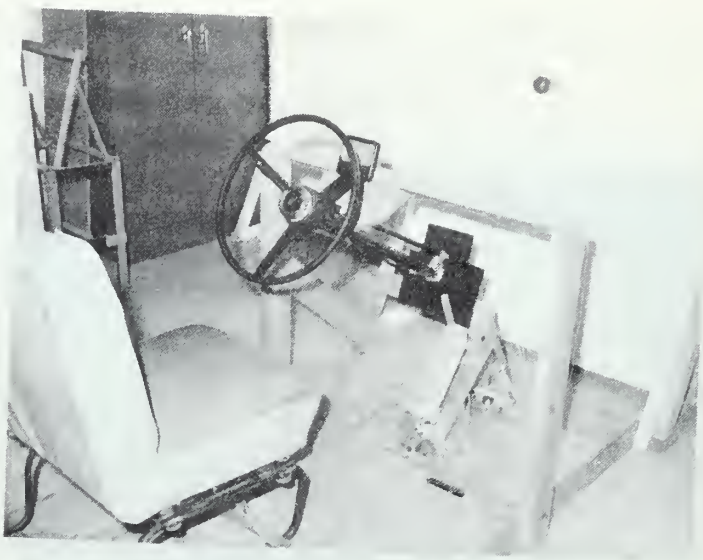

FIGURE 3. Test "Vehicle"

V. RESULTS

The dependent variable measured in this experiment was the brake actuation time defined as the length of time elasped from when the stop light light was activated until the pedal was depressed 1/16th of an inch.

Table II and Table III show the number of actuations occurring within 10 millisecond intervals. Table II has Pedal I and Pedal II plotted with the 45° angle results. The mean brake actuation times for the pedals at the 45° angle were 235 milliseconds for Pedal I and 224 milliseconds for Pedal II. Table III has Pedal I and Pedal II plotted with the 60° angle results. The mean brake actuation times for the pedals at the 60° angle were 226 milliseconds for Pedal I and 222 milliseconds for Pedal II.

A two way analysis of variance was performed on the actuation times. This analysis is shown in Table IV. The results of this analysis showed:

1) there was a significant difference (Pedal II was best) between Pedal I and Pedal II at the .01 level.

2) there was not a signficant difference in the pedal angles at the .05 level.

3) there was not a significant interaction between the pedal type and the pedal angle.

A Wilcoxon Matched-Pairs Signed-Ranks Test was performed on Pedal I versus Pedal II at the 45° angle and the 60° angle. The 45° angle test resulted in a $Z = -3.38$ and $p = .0005$ which showed that Pedal

II was significantly faster than Pedal I at the .01 level. The 60° angle test resulted in a $Z = .46$ and $p = .3228$ which showed that there was no difference between the pedals at the .01 level.

TABLE I: SUMMARY OF BRAKE ACTUATION TIME EXPERIMENTS

Experiment	Subjects					Brake Actuation Times		
	Average Age	Average number of years of driving experience	Number			Left foot on brake	Conventional method of braking	Right foot on integrated brake accelerator pedal
			Male	Female	Total			
Belzer and Huffman	15 years	None	24	24	48	.247 seconds	.418 seconds	-----
Konz, Koe and Kalra using Winkleman pedal design	28 years	Unknown	---	---	25	.29 seconds	.45 seconds	.36 seconds
Konz, Koe and Kalra using pedal designed by Koe	Unknown	Unknown	Some	Some	72	-----	.435 seconds	.323 seconds
Konz, Koe and Kalra using pedal designed by Koe	23 years	5 years	11	5	16	-----	-----	1) .334 seconds 2) .2815 seconds

1) Average of the Minimum average brake actuation times for each subject.
2) The minimum condition average actuation time of the quickest subject.

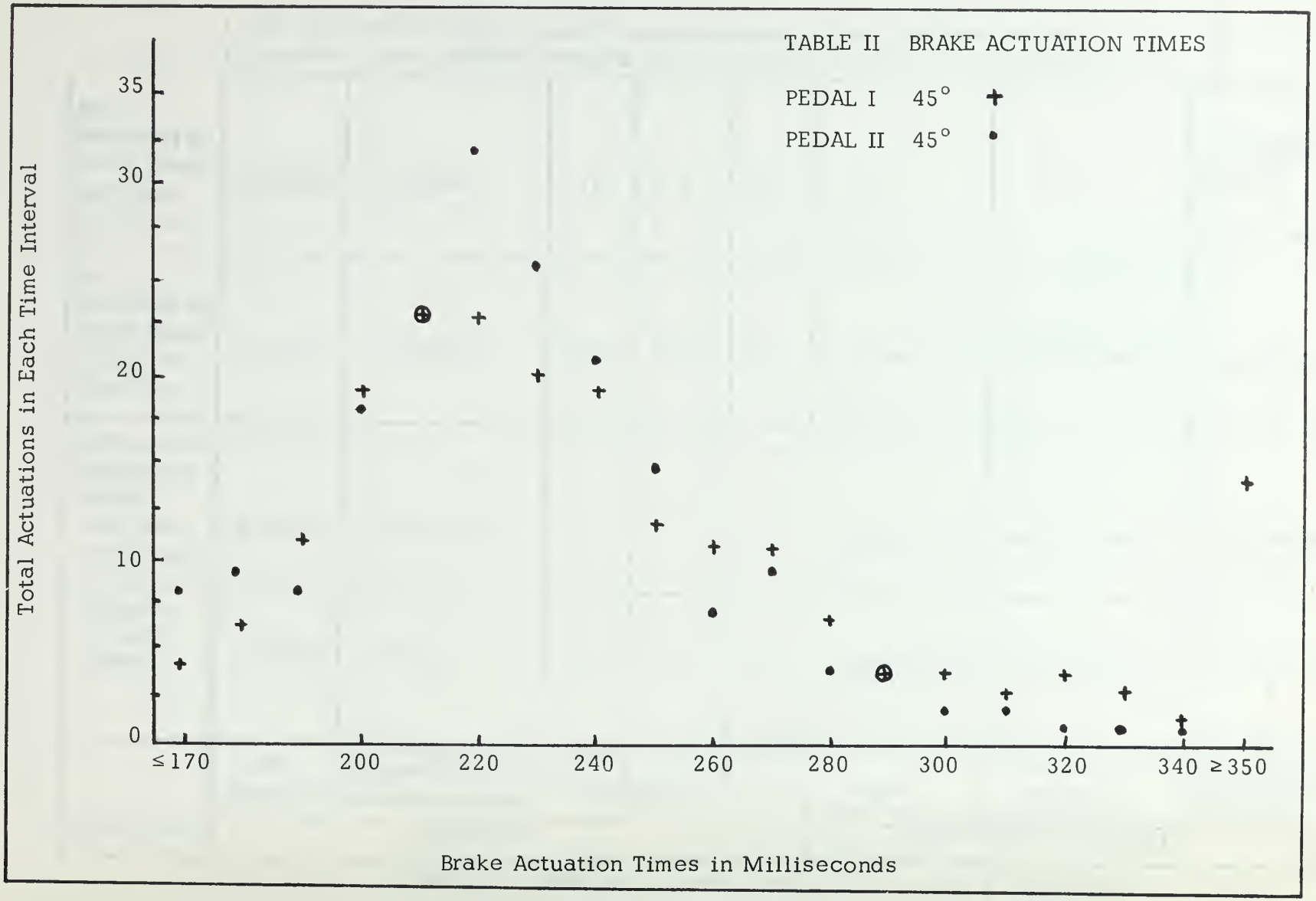
TABLE II BRAKE ACTUATION TIMES
PEDAL I 45°
PEDAL II 45°
Total Actuations in Each Time Interval
0
10
20
30
35
≤170
200
220
240
260
280
300
320
340
≥350
Brake Actuation Times in Milliseconds

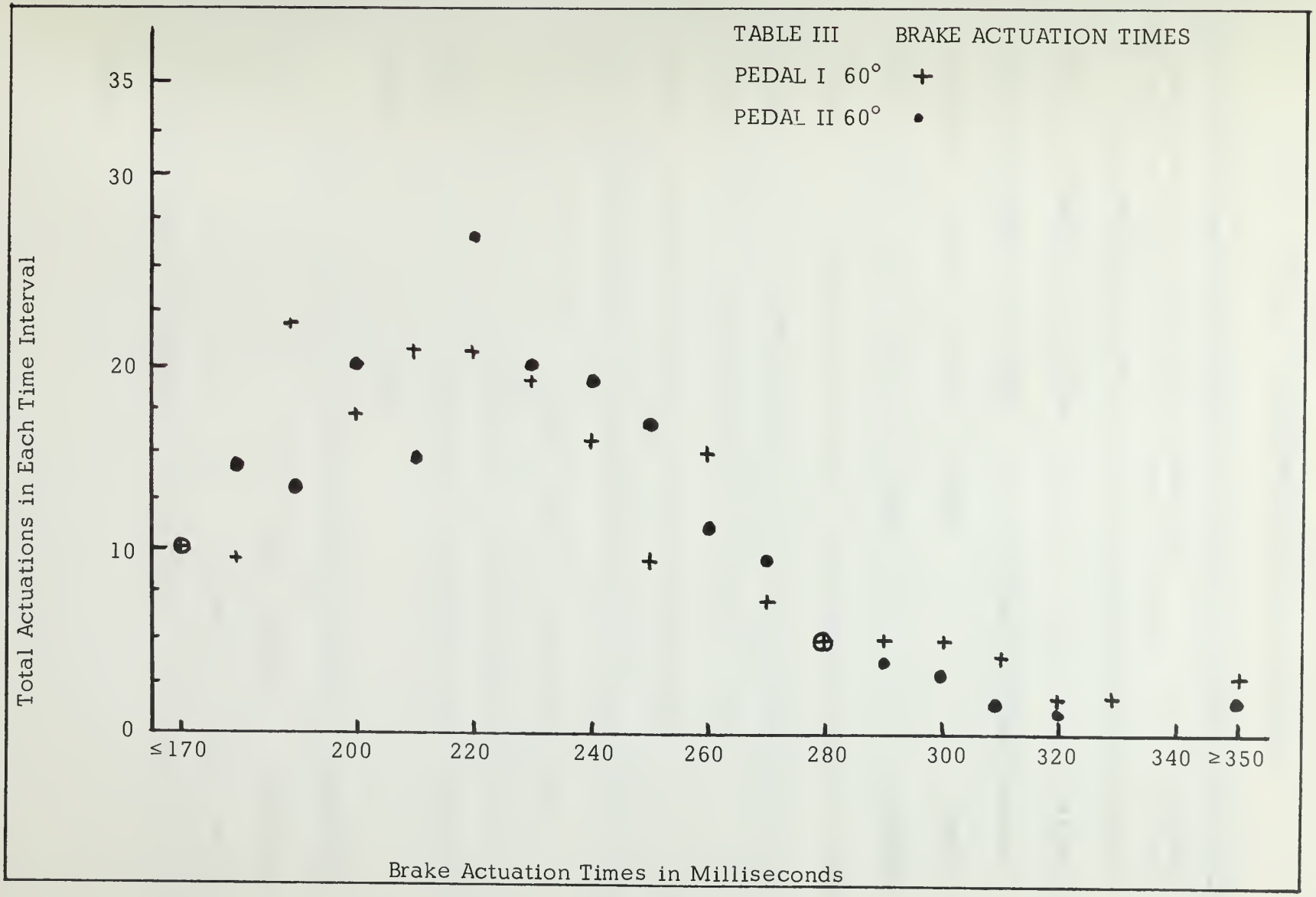
TABLE III BRAKE ACTUATION TIMES
PEDAL I 60°
PEDAL II 60°
Total Actuations in Each Time Interval
0
10
20
30
35
≤170
200
220
240
260
280
300
320
340
≥350
Brake Actuation Times in Milliseconds

TABLE IV

ANALYSIS OF VARIANCE ON BRAKE ACTUATION TIMES

SOURCE	df	MS	F	P
Angles	1.	5 88.	3.229	< .10
Pedals	1.	1 752.	6.824	< .01
Angles X Pedals Interaction	1.	2368.	1.503	< .25
Error	764.	1576.		
Total	767.			

VI. DISCUSSION AND CONCLUSIONS

The results of this experiment have shown that Pedal II is significantly faster than Pedal I at the 45° angle.

The fastest mean actuation time was Pedal II at the 60° angle. The Wilcoxon Matched-Pairs Signed-Ranks Test showed no difference between the pedals at this angle. Thus, there has been a determination that Pedal II is better at the 45° angle and that the Pedals are about equal at the 60° angle. This result may be attributed to the fact that the angle between the accelerator post and the control pedal surface varied between Pedal I and Pedal II requiring additional pressure to be exerted by the toe to accelerate when using Pedal I at the 45° angle. This in turn would tend to raise the heel and thus more time is required to actuate the brake. This indicates that additional research should be conducted into the best spring pressures for the brake post and for the accelerator post.

The Ss were very uncomfortable when the pedals were set at the 60° angle. If this angle is used in further research the seat should be adjusted to about 65% of the Ss' heighth.

Some Ss explained that they normally drove with their right foot turned to the right. Further research could be conducted to determine if there is a more comfortable angle. A constant 0° of rotation was used in this experiment and angles of 15°, 30° and 45° should be tested in the future.

The brake actuation times obtained in this experiment compare favorably with other experiments previously conducted. Comparing the Pedal II 60° angle average brake actuation time of 222 milliseconds with the times listed in Table I the differences are as follows:

1) .025 seconds faster then the fastest left foot braking average time.

2) .196 seconds faster then the fastest conventional braking time.

3) .101 seconds faster then the fastest average time using the integrated brake-accelerator pedal.

Although these are comparisons of times obtained over a wide range of Ss, comparison 2 and 3 indicate that further experimentation with Pedal II is warranted.

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13. ABSTRACT

This experiment was performed to evaluate the effect of the integrated brake-accelerator pedal on the reduction of brake actuation time. The pedals were designed so that the drivers could accelerate with the toe of their right foot while the right foot was resting on the brake. Pedal I was of a hinged design and Pedal II was of a one piece design. 48 Ss were used to test the two integrated brake-accelerator pedals at angles of 45° and 60°. The task was to depress the accelerator to a required level and then depress the entire pedal when a red light was activated. The brake actuation time was the time elapsed between onset of the light and 1/16th inch depression of the pedal. Results showed a significant difference ($p < .01$) between the pedals with the one piece design performing the fastest. The mean brake actuation time for this pedal at 60° angle was 222 milliseconds. This is 101 milliseconds less than the mean brake actuation time of the next fastest integrated brake-accelerator pedal design. The results support further experimentation with the one piece pedal with the prospect of further reducing the brake actuation time.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Integrated Brake-Accelerator Pedal						
Brake Reaction Time						
Brake Actuation Time						
Automobile - Man Machine System						
Increased Safety Due to Faster Braking Time						
Brake Pedal						
Accelerator Pedal						